

ARL-TM-2015 ● DEC 2015



# **Volume I: Select Presentations**

by ARL Summer Student Research Symposium

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# **Volume I: Select Presentations**

by ARL Summer Student Research Symposium

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1. REPORT DATE (DD-MM-YYYY)	2. REPORT TYPE			3. DATES COVERED (From - To)	
December 2015	Final				
4. TITLE AND SUBTITLE				5a. CONTRACT NUMBER	
Volume I: Select Presentations					
				5b. GRANT NUMBER	
			5c. PROGRAM ELEMENT NUMBER		
6. AUTHOR(S)				5d. PROJECT NUMBER	
ARL Summer Student Research	Symposium				
				5e. TASK NUMBER	
				5f. WORK UNIT NUMBER	
7. PERFORMING ORGANIZATION NAMI	E(S) AND ADDRESS(ES)			8. PERFORMING ORGANIZATION REPORT NUMBER	
US Army Research Laboratory					
2800 Powder Mill Road Adelphi, MD 20783-1138			ARL-TM-2015		
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)				10. SPONSOR/MONITOR'S ACRONYM(S)	
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			11. SPONSOR/MONITOR'S REPORT NUMBER(S)		
12. DISTRIBUTION/AVAILABILITY STATEMENT					
Approved for public release; distribution is unlimited.					
13. SUPPLEMENTARY NOTES					
14. ABSTRACT					
The ARL Summer Student Research Symposium is an ARL Director's Award Program for all the students participating in various summer scholarship and contract activities across ARL. The goal of the program is to recognize and publicize exceptional achievements made by the students and their mentors in the support of Army science.					
All college undergraduate and graduate students receiving research appointments and conducting summer studies at ARL are automatically enrolled in the symposium program. As an integral part of their summer study, all students are required to write a paper on their work which summarizes their major activity and its end product.					
The program is conducted on two separate competitive levels: undergraduate and graduate. The format of the paper in both levels is the same. However, the evaluation will take into consideration the difference in the academic level of the students.					
All students submitted their research paper for directorate review. Directorate judging panels selected one or two papers from each competition category for the laboratory-wide competition at the Summer Student Symposium on 7 August 2015.					
Students selected by their directorate for competition participated in the one-day Summer Student Symposium on 7 August 2015. At the symposium the students gave presentations on the focuses of their research papers to the ARL Director and an ARL Fellows panel.					
This volume of the Summer Student Symposium Proceedings contains many of the presentations that the selected students gave at the symposium.					
15. SUBJECT TERMS					
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#### **Director's Foreword**

The U.S. Army Research Laboratory (ARL) mission is to "Provide innovative science, technology, and analyses to enable full spectrum operations." As the Army's corporate laboratory, we provide the technological underpinnings critical to providing capabilities required by our current and future Soldiers.

Our nation is projected to experience a shortage of scientists and engineers. ARL recognizes the criticality of intellectual capital in generating capabilities for the Army. As the Army's corporate laboratory, addressing the projected shortfall is a key responsibility for us. We have, therefore, identified the nation's next generation of scientists and engineers as a key community of interest and have generated a robust educational outreach program to strengthen and support them. We have achieved many successes with this community. We believe that the breadth and depth of our outreach programs will have a significant positive effect on the participants, facilitating their journey toward becoming this Nation's next generation of scientists and engineers.

A fundamental component of our outreach program is to provide students research experiences at ARL. During the summer of 2015, we supported research experiences at ARL for over 175 undergraduate and graduate students. Each of these students writes a paper describing the results of the work they performed while at ARL. All of the papers were of high quality, but only a few could be selected for presentation at our student symposium. Several of the presentations for the selected research papers prepared this summer are contained in this volume of the proceedings, and they indicate that there were many excellent research projects with outstanding results. It is unfortunate that there was not enough time for us to have all of the papers presented. We would have enjoyed hearing them all.

We are very pleased to have hosted this outstanding group of students for the summer. It is our hope that they will continue their pursuit of technical degrees and will someday assist us in providing critical technologies for our Soldiers.

Thomas P. Russell

Director

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#### Introduction

The ARL Summer Student Research Symposium is an ARL Director's Award Program for all the students participating in various summer scholarship and contract activities across ARL. The goal of the program is to recognize and publicize exceptional achievements made by the students and their mentors in the support of Army science.

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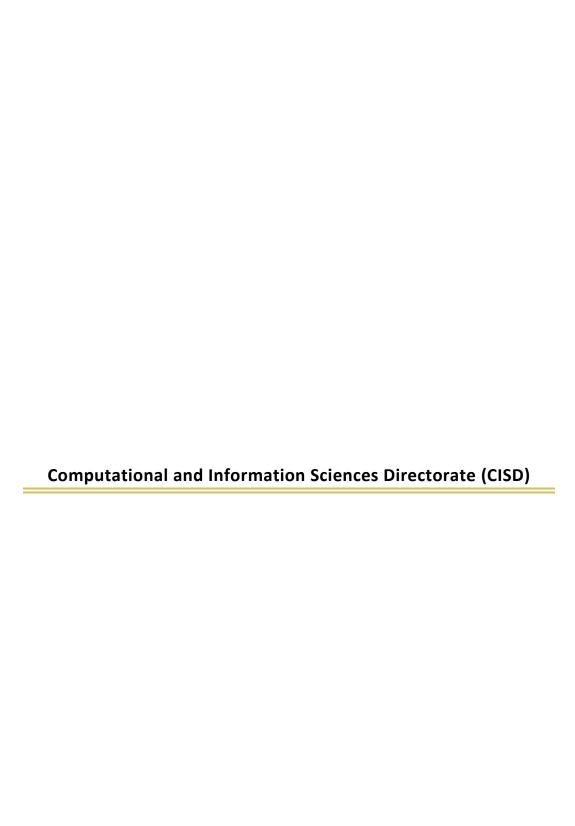
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This volume of the Summer Student Symposium Proceedings contains many of the selected presentations given at the symposium.

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# Enhanced Experience Replay for Deep Reinforcement Learning

August 7, 2015

## **Bryan Dawson**

Senior – University of Maryland Baltimore County Computer Science

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Introduction



- The Army of the future will require many autonomous systems.
- Impossible to build robust systems using hardcoded rules.
- Battlefield environment is dynamic and unpredictable.
- Need to develop adaptive algorithms to handle these challenges.



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# **Reinforcement Learning**



- Unsupervised learning through experience
- · Agent develops policy through exploration
- Actions Consequences
- · General learning paradigm

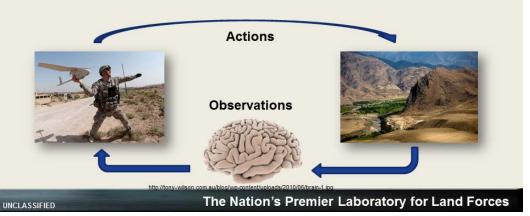


us ARMY Experience Replay





- A single experience can improve the policy at any point in time
- Must utilize all information you can gather
- Removes recency bias and reduces variance across updates





# Army = Video Games ?



#### **Army Battlefield Strategy**

- 1) Collect data from distributed sensors
- 2) Analyze data
- 3) Develop/decide on strategy
- 4) Take action (troop movement, etc.)



#### Video Game

- 1) Collect pixels from game output
- 2) Analyze data
- 3) Develop/decide on strategy
- 4) Take action (move Mario, etc.)



http://www.mariogames.name/mario\_image/super-mario-bros-deluxe.jpg

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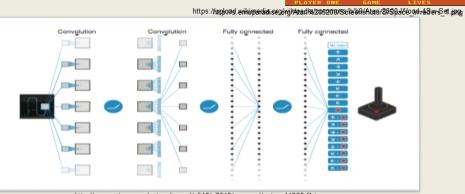


# **Atari Deep Learning**



- Uses a convolutional neural network
- Raw frame expected value of actions
- 10 days of training on 2496 cores!

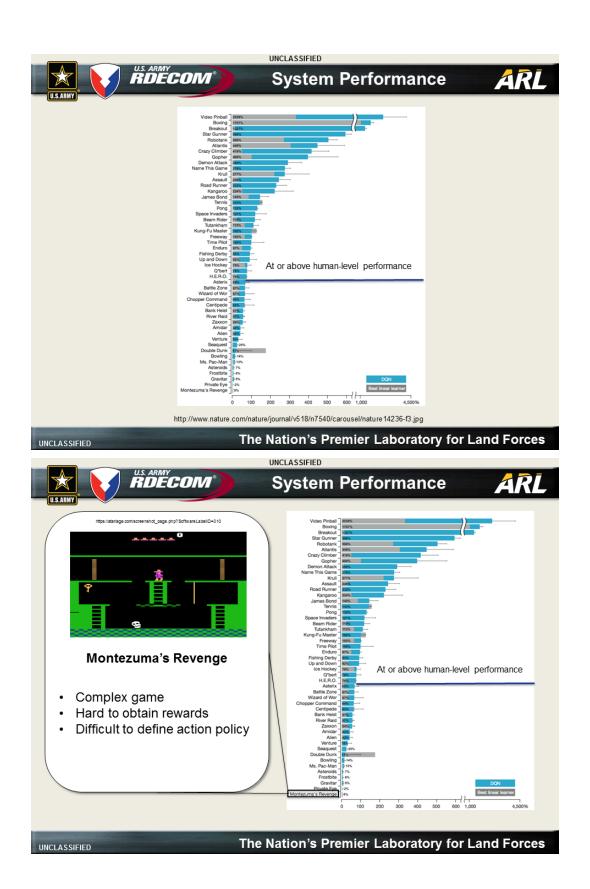


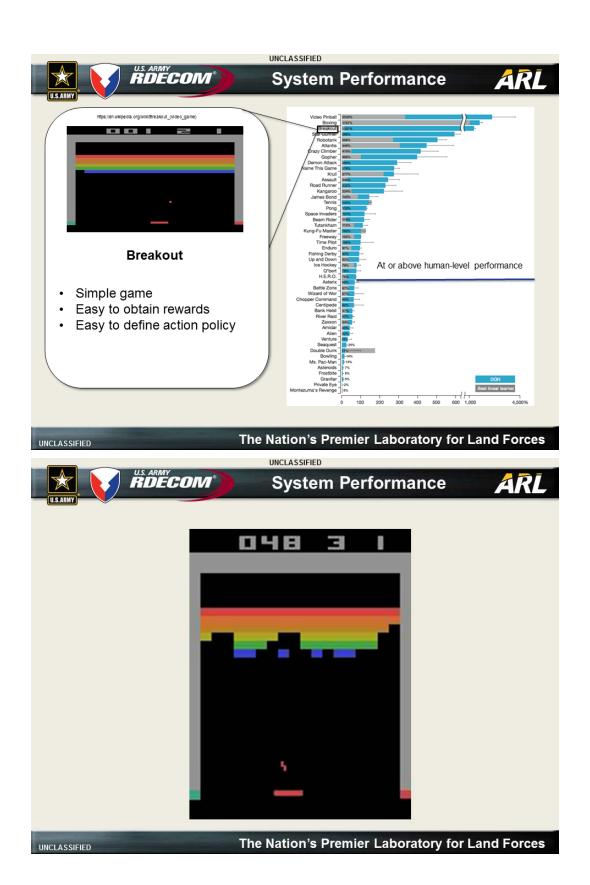


http://www.nature.com/nature/journal/v518/n7540/carousel/nature14236-f1.jp

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# **Reward-Biased Replay**

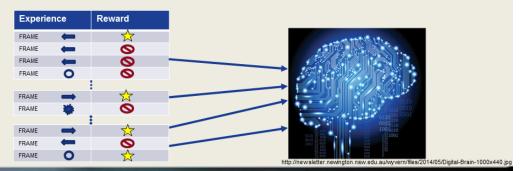


#### Problem:

- Default sampling does not emphasize winning.
- Delayed reward signal hard to correlate actions with rewards.

#### Solution:

• When the agent receives a reward, perform extra policy updates with recent experiences.



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**Reward-Biased Replay** 

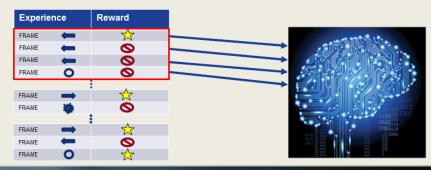


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# Representation Pre-training ARL

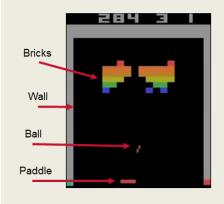


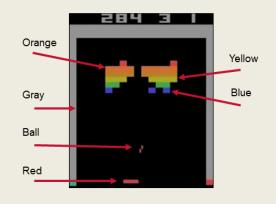
#### Problem:

· Agent learns how to represent the game as it learns what to do with those representations.

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Evolving representations negatively affect learning.





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Representation Pre-training

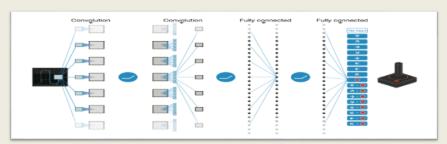


#### Problem:

- Agent learns how to represent the game as it learns what to do with those representations.
- Evolving representations negatively affect learning.

#### Solution:

- Allow system to train normally until a performance threshold.
- Lock convolutional layers and retrain linear layers from scratch.



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# Representation Pre-training ARL

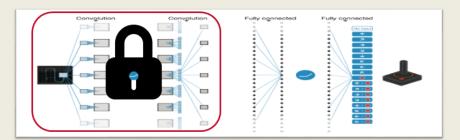


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Representation Pre-training

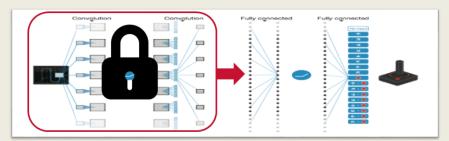


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## Repetition Inhibition

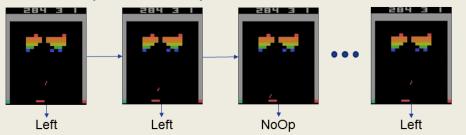


#### Problem:

- Game keeps getting stuck in loops.
- Loops during training can oversaturate replay memory.

#### Solution:

- · Examine most recent frames during training.
- If current frame has been seen recently, make random move instead of following policy.
- · Break loops and force exploration.



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Repetition Inhibition

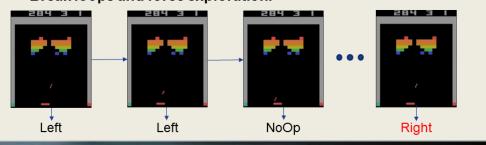


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# **Preliminary Results**



## Representation Pre-training

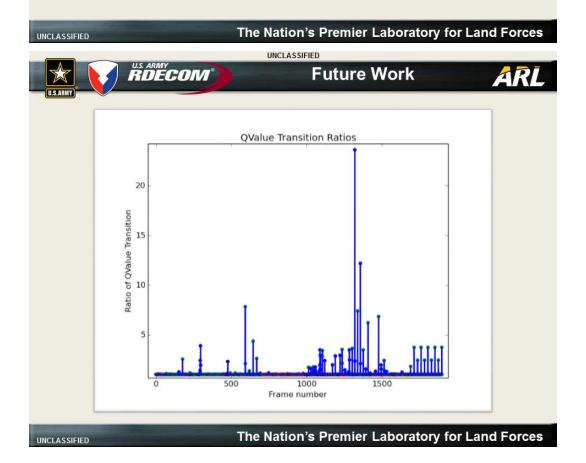
- · Achieved reported performance in ONE day of training.
- 10x Speed-up!
- · Can test algorithmic adjustments in significantly less time.

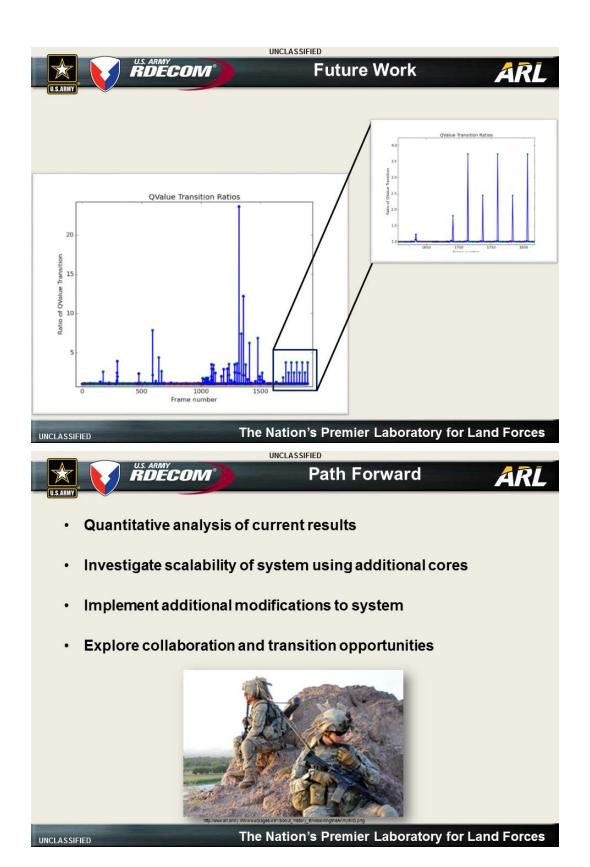
#### Repetition Inhibition

- ~50,000 loops were identified and avoided during training.
- · Loops still encountered during preliminary testing.

#### **Reward-Biased Replay**

- · Successfully sampled actions that triggered rewards.
- Evaluating our results to determine the effect on the system.







# Acknowledgements



# A sincere thank you to

- · Dr. David Doria
- Dr. Raju Namburu
- · CISD
- Fellow interns

#### Questions?



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# Dislocation Density Evolution for FCC Materials Under Shock Loading

Presented by: Karoon Mackenchery<sup>1</sup>

Advisors: Dr. Rama Valisetty<sup>2</sup>, Dr. Avinash Dongare<sup>1</sup>

- 1. University of Connecticut, Storrs, CT
- 2. Army Research Lab, Aberdeen Proving Ground, MD

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**Outline** 



- 1. Motivation
- 2. Need
- 3. Defects in Metals
- 4. Impact Loading conditions
- 5. Molecular Dynamics background
- 6. Specific Objective
- 7. Computational Details
- 8. Results
- 9. Future Work

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#### Motivation



- Materials used for current armored applications possess high yield strengths; however, tend to fail in conditions of **extreme environments** (high velocity impact loading, temperatures, pressures, etc.)
- There exists a need to enhance the properties of next generation of armored materials
  - withstand multiple high velocity impacts
  - retain high yield strengths
  - lightweight



 The design of improved armored materials to be used in extreme environments require enhanced performance and minimal degradation

 $1.\ National\ Research\ Council.\ \textit{Opportunities in Protection Materials Science and Technology for Future\ Army\ Applications.}\ Washington,\ DC:\ The\ National\ Academies\ Press, (2011)$ 

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#### Need



- Microstructure, chemistry, deformation behavior, degradation behavior all play an important role in the impact (shock) failure of metallic materials.
- For a material under impact loading, failure at the macroscale has been observed to be due to the micromechanical response at the atomic scale, where **nanovoids are generated and coalesce** to contribute to the cracking and subsequent failure of the material.
- In metals, the mechanical behavior is largely determined by the **evolution of defects** (twins, dislocations, stacking faults, voids, etc.).

Evolution of defect structures determined by a number of factors:

- Microstructure
- Loading conditions
- Temperature of the system
- Pressures
- A need to examine the contribution of the evolution of defect structures to the failure response in metallic systems under impact loading
- 2. A. M. Dongare, B. LaMattina, and A. M. Rajendran, Atomic Scale Studies of Spall Behavior in Single Crystal Cu, Procedia Engineering 10, 3636 (2011).

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#### Defects in metallic materials



Metallic materials contain crystal-like structures where atoms are arranged in a certain orientation, then repeated throughout the material

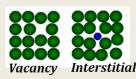
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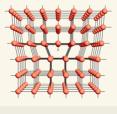
A number of different types of defects located within crystal structure:

-Point defects: interstitials, vacancies

-1-D (linear): dislocations
-2-D (planar): stacking faults
-3-D (bulk): voids, impurities

Plasticity within deformed materials due to glide of dislocations throughout material





Perfect
Shockley Partial
Stair-rod
Hirth
Frank
Twin

Dislocation Types

Example of Dislocation

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Impact Loading

Flyer plate

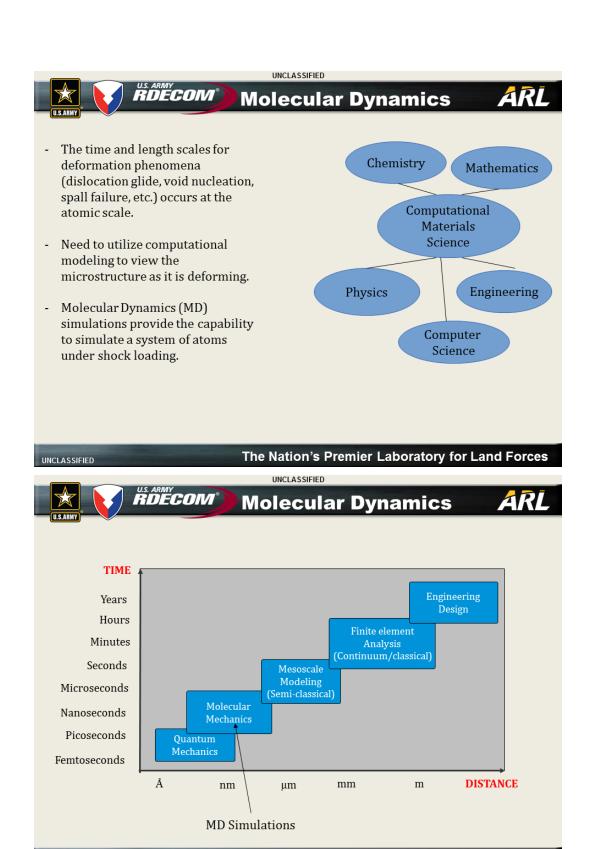
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Spallation

Spallation

- Experimentally impact loading achieved through plate impact or laser pulse to study shock response of materials.
- Impact generates compressive waves in the flyer plate and target.
- Compressive waves reflect from free surfaces as tensile waves that interact .
- Nucleation of voids, growth, and coalescence to form microscopic cracks and ultimately failure (Spallation).

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# **Objective**



# Objective: Investigate the effects of the evolution of defect densities on the failure of FCC metallic materials

- Run large scale shock loading MD simulations for various metallic materials (Single crystal Al, Cu)
- Identify and characterize various types of dislocations present through simulation using *CrystalAnalysis Tool*
- Investigate the relationship between failure, defect evolution, defect type, and other important factors:
  - Material type
  - Microstructure
  - Loading conditions

2. A.Stukowski and K. Albe, Extracting dislocations and non-dislocation crystal defects from atomistic simulation data, *Modelling Simul. Mater. Sci. Eng.* 18,085001 (2010)

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# **Computational Details**



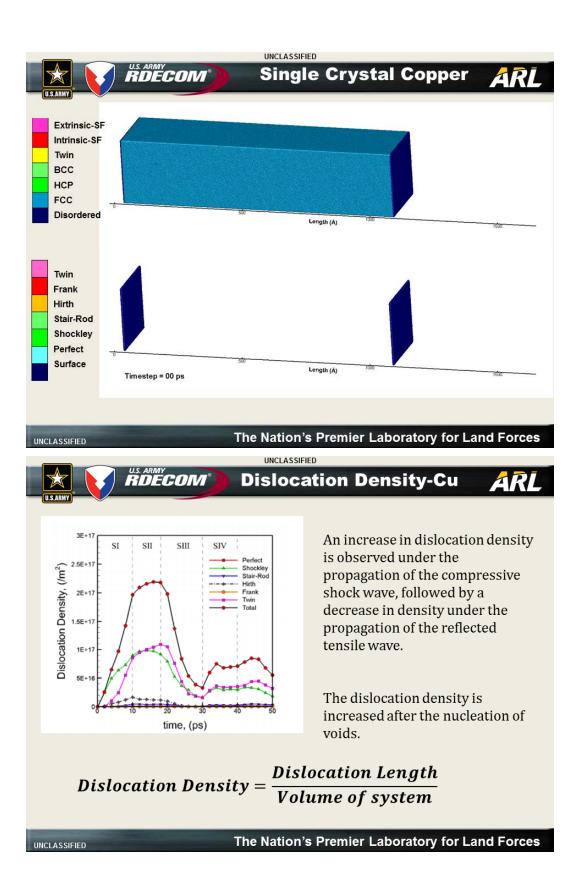


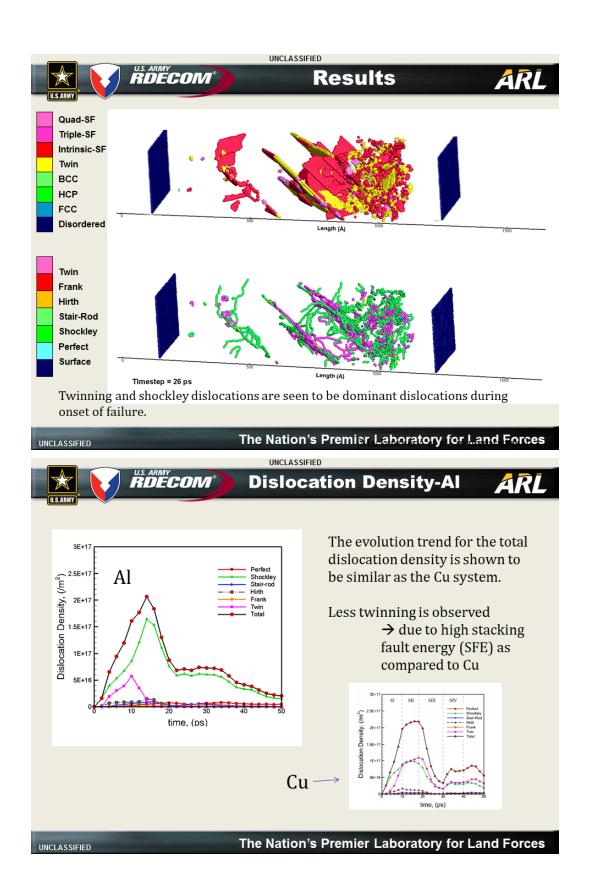
- Create a rectangular box system (long in impact direction) consisting of same type of atoms

Length (A)

- Designate first 3 nm of system as piston
- Provide the atoms in the piston region a constant impact velocity (1 km/s) for a given duration (10 ps)
- Release impact and observe the system evolve as the shock waves travel and reflect within the system
- Post Processing: Characterize different types of dislocations within system

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## **Conclusions**



- MD simulations have been run for single crystal Cu and Al under shock loading simulations
- Dislocations and defects identified and characterized
- Same trend observed for total dislocation density evolution in both systems
- Twinning seen to be one of dominant dislocations in Cu, but not in Al
  - Observed in literature as well

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#### **Future Work**



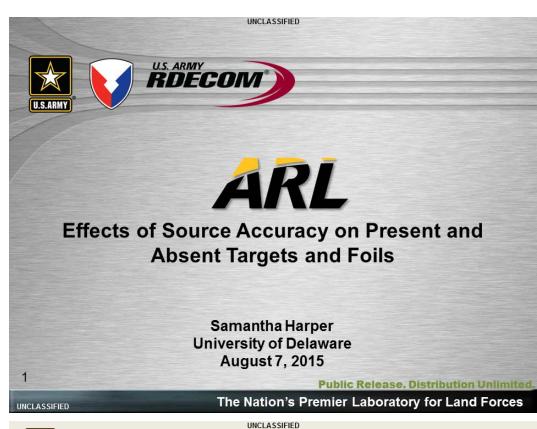
Run shock loading simulations and extend dislocation analysis for:

- Different materials and crystal structures (HCP, etc.)
- Larger systems (>1 billion atoms)
- Different loading conditions (impact velocity, orientation, temperature, etc.)
- Different microstructures (nanocrystalline, etc.)

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Human Research & Engineering Directorate (HRED)

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**Outline** 



- 1. Background
- 2. Study: Method and Results
- 3. My Project
  - 1. Method
  - 2. Results
- 4. Conclusions and Future Directions

2

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#### Introduction



- Intelligence Analysis
- Trust
- Eye Tracking
  - Observe search patterns
  - Insight into the decision making process
  - Examine which types of information are more useful than others

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# Methodology



- Participants: 13 ARL employees
- 96 scenes: 4 High Value Targets (HVTs) and 4 Foils

#### Independent variables:

- Intel Source Accuracy: 90% vs. 60%
- HVT Volume: Number of HVTs described at once (1, 2 or 4)

# Dependent variables:

- Decision Accuracy
- · Ratings of Difficulty, Confidence, and Trust
- · Eye movements: number of fixations

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## **Hypotheses**



#### Trust:

 Participants will learn that one source is more accurate than the other and trust the accurate source more

#### Eye tracking:

- Individuals will look more often at absent High Value Targets (HVTs) with the 60% Intel Source than the 90% Intel Source
- Individuals will look at absent HVTs and Foils the same amount with the 90% Intel Source

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**Procedure** 

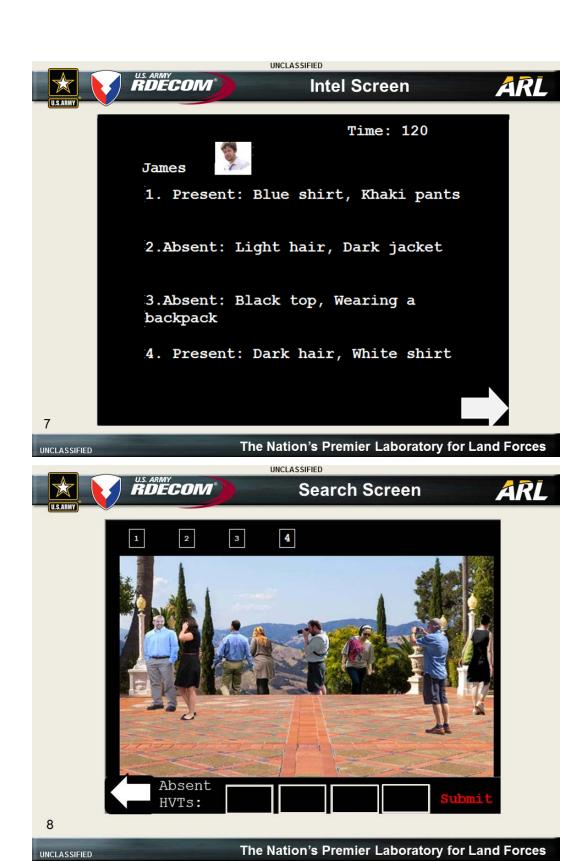


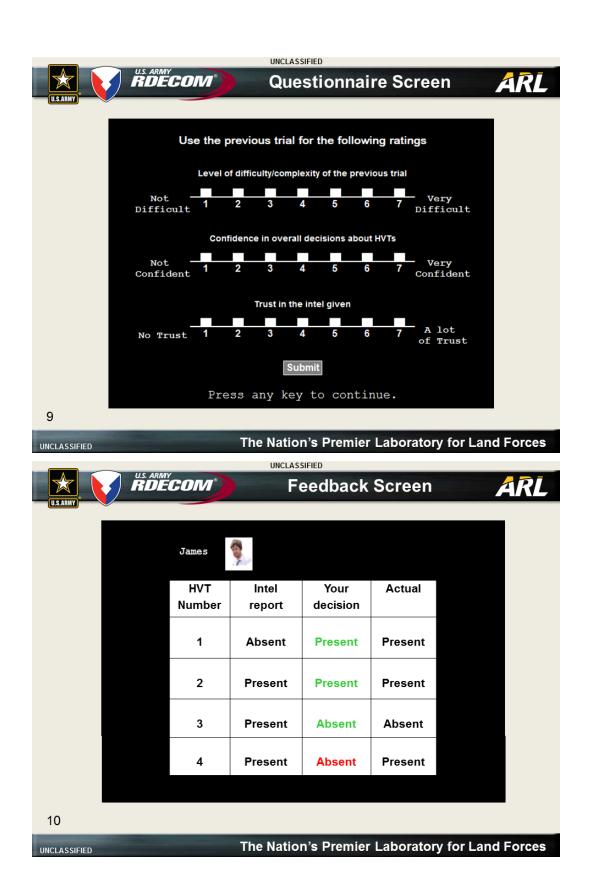
#### Trial:

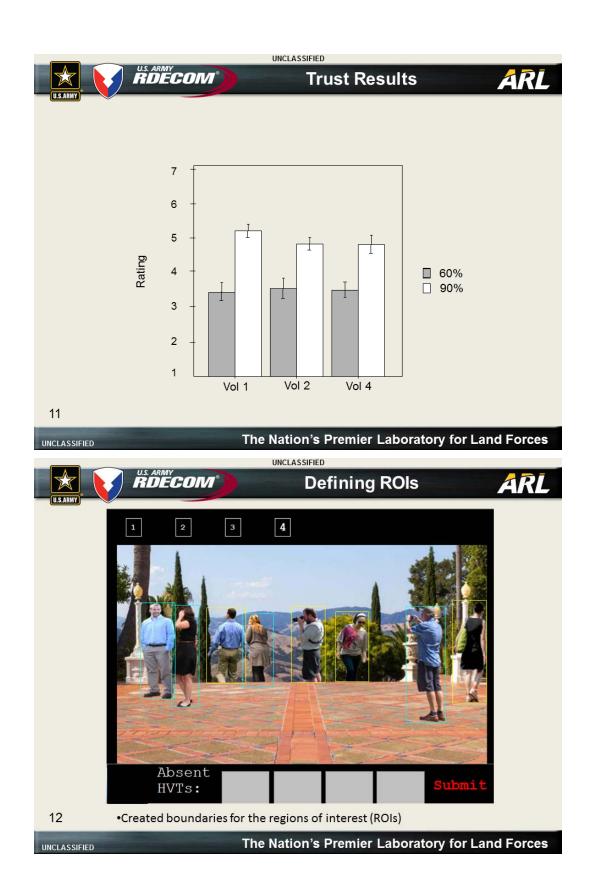
- Intel Screen
- Search Screen
- Questionnaire Screen
- Feedback Screen

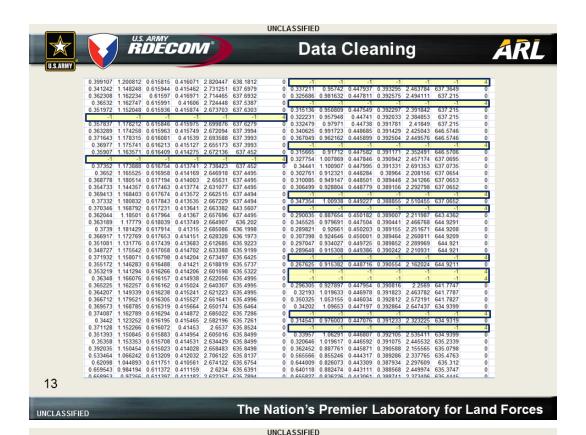
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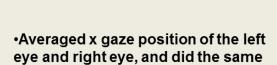
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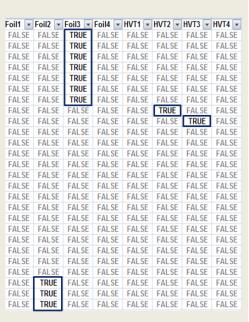


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Converted these data into pixels

for the y position

- •Used gaze data and ROI boundaries to determine if a fixation was in a ROI
- •Calculated absent and present from the Intel's best guess

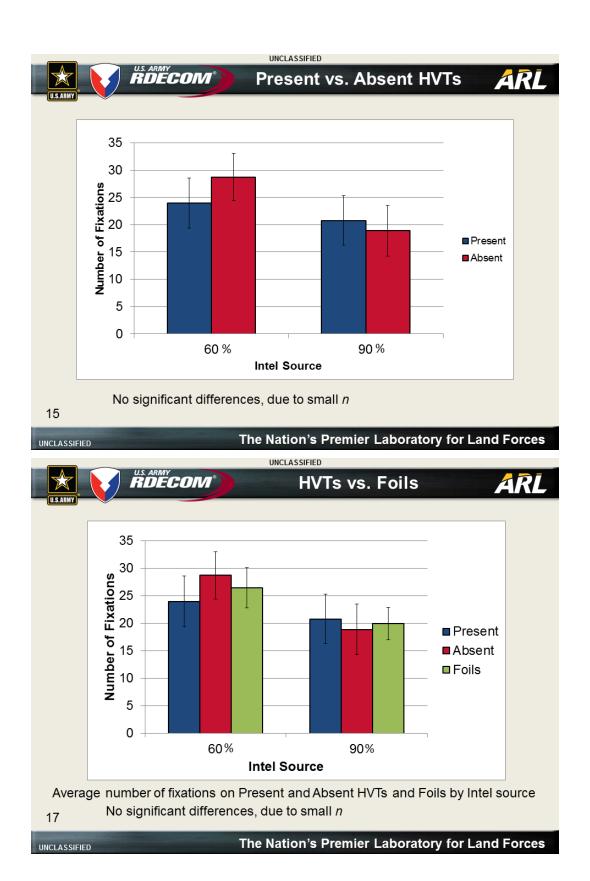


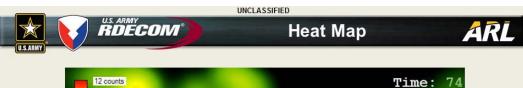
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**Defining Gaze Position** 







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Conclusions



#### Eye tracking:

- · No statistical significance found
- With the 60% Intel Source, participants looked more at absent HVTs than present HVTs
- With the 90% Intel Source, participants looked less at all ROIs, and looked at Foils and absent HVTs less than present HVTs

#### Trust:

- Participants trusted the 90% Intel Source
- · Soldiers search more efficiently with trusted sources

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# **Acknowledgments**



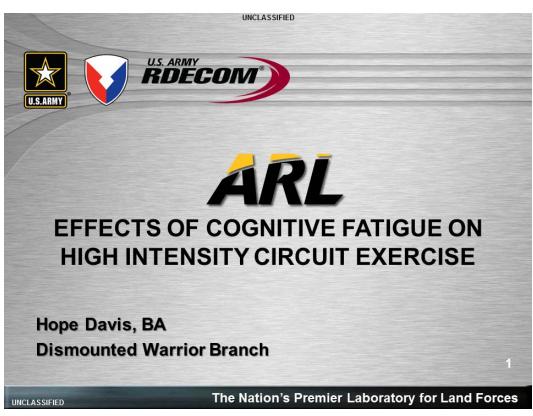
I would like to thank my mentors Katherine Gamble and Debbie Patton and the Cognitive Sciences Branch.

Thank you!

Questions?

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Introduction

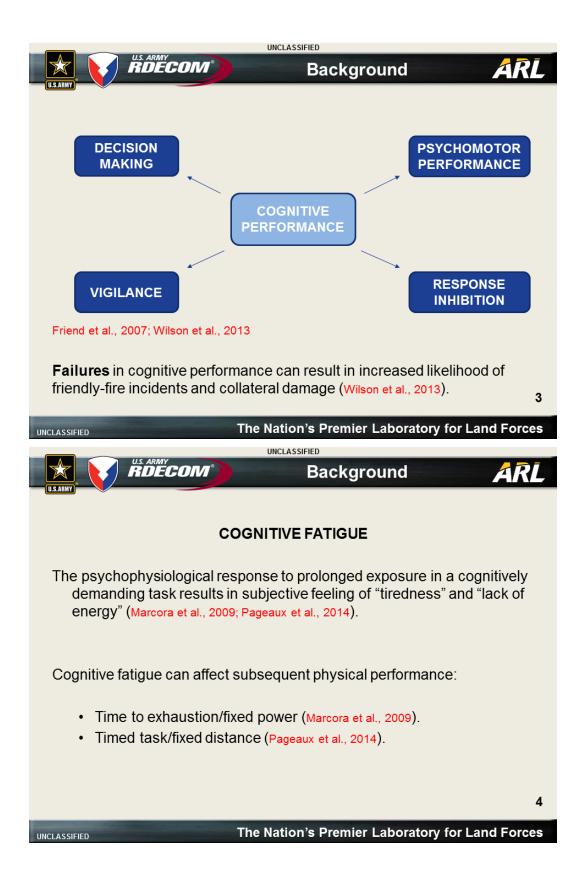


#### MY CONTRIBUTIONS:

- · Data collection
- · Formation of hypotheses
- · Data reduction
- · Statistical analysis

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## **Background**



#### WHY SHOULD WE CARE?

- With increasingly sophisticated communication devices, cognitive fatigue may continue to be a relevant issue for the Soldier.
- When cognitively fatigued individuals reach high levels of exertion, they
  are more likely to disengage from the physical task (Marcora et al., 2009;
  Pageaux et al., 2014).
- Soldiers must transition between physically demanding tasks for an extended amount of time, i.e., high intensity circuit training.

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#### **Hypotheses**



- 1. Number of overall repetitions completed will be **lower** after completing a cognitively fatiguing task.
- 2. Time-on-task during the physical exercise will **decrease** after a vigilance task compared to the control task.
- 3. When separating the 20-minute physical task into quartiles (5-minute segments), time-on-task will be most affected in the **first period** when preceded by the cognitively fatiguing task.
- 4. Physiological measurements (oxygen uptake and caloric expenditure) will see **no change**.

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#### **Methods**



Seven male and 4 female participants (goal n =30) completed 2 sessions of a vigilance or video (control) task (50 minutes) followed by a timed (20 minute) circuit-workout.

#### Vigilance task

• low Go/ high No-Go (Marcora et al., 2009)

#### Video task (control)

• Documentary (Luxury Trains of the World) used in previous paradigms (Pageaux et al., 2014).

#### Physical Task

- 20 minutes, as many repetitions as possible
- · Circuit of 5 pull-ups, 10 push-ups and 15 squats

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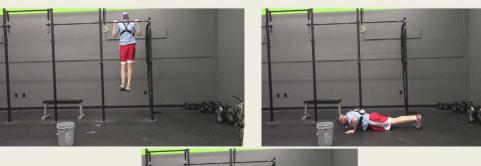
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**Methods** 





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8

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#### **Methods**



- · Data Reduction
  - Total repetitions was calculated.
  - Time-on-task (TOT) was measured in seconds with video observation.
  - TOT was also separated into four 5-minute segments within the circuit exercise task to examine time effects of the vigilance task.
  - · Mean value of oxygen uptake and caloric expenditure calculated.
- · Statistical Analysis
  - Repeated measures t-tests determined differences between cognitive tasks for repetitions, TOT, and physiological measurements.
  - Repeated measures ANOVA examined effect of time and the vigilance task on TOT.

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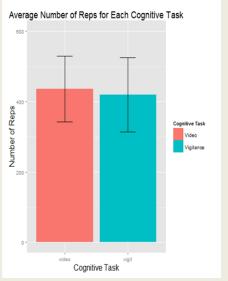
#### Results



#### **REPS vs. COGNITIVE TASK**

Contrary to the hypothesis, there was no significant difference in the total number of reps between cognitive tasks (p = 0.18).

Cognitive Task	Mean (Reps)	Standard Deviation		
Video (control)	436	93		
Vigilance task	420	106		



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#### Results

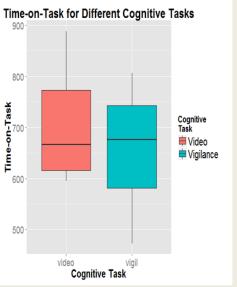
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#### TIME ON TASK vs. COGNITIVE TASK

TOT values significantly decreased by 3% (37 seconds; p < 0.029) after a vigilance task compared to a control video.

	Cognitive Task	Mean (Seconds)	Standard Deviation
1	Video (control)	699.8348	100.0143
2	Vigilance	662.7567	108.4477



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Results

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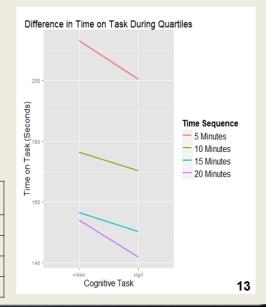
#### TIME ON TASK FOR QUARTILES

There is no interaction between the cognitive task and the quartile (p = 0.97).

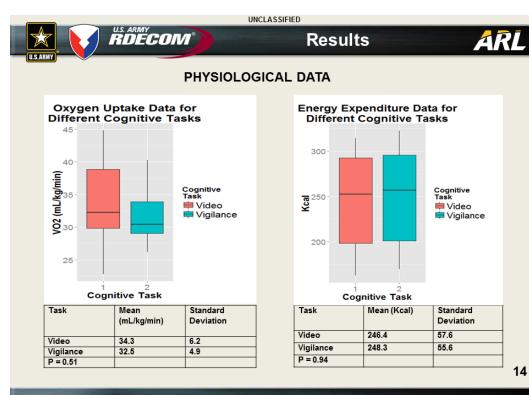
There is a significant difference in the time on task between each quartile (p < 0.005).

There is no significant difference in time on task between cognitive tasks (p = 0.143).

Quartile	Mean (seconds)	Standard Deviation	
1	206.8	27.2	
2	173.3	31.5	
3	153.4	28.2	
4	147.8	31.4	



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#### Discussion



So far, the circuit task demonstrates that performance is decreased by 3%.

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Similar to findings in past literature:

- 6% increase in timed run (Pageaux et al., 2014)
- 15% decrease in time to exhaustion (Marcora et al., 2009)

The discontinuous nature of the present study is potentially more operationally relevant than constant stretch-shortening-cycle tasks performed in previous studies.

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#### **Future Research**



#### COGNITIVE PSYCHOLOGY

Dr. Head's ongoing study examines the effects of cognitive fatigue on subsequent marksmanship in Soldiers.

#### **PHYSIOLOGY**

- 1. Creating a technique to mitigate effects of cognitive fatigue in Soldiers in the field (automated devices).
- 2. Sex differences in response to stress (progesterone during menstrual cycle).
- 3. Changes in biomechanics/predisposition to injury.

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#### **CITATIONS**



- Friedl, K. E., Grate, S. J., Proctor, S. P., Ness, J. W., Lukey, B. J., & Kane, R. L. (2007). Army research needs for automated neuropsychological tests: Monitoring soldier health and performance status. *Archives of Clinical Neuropsychology*, 22, 7-14.
- Marcora, S. M., Staiano, W., & Manning, V. (2009). Mental fatigue impairs physical performance in humans. *Journal of Physiology*, 106, 857-864.
- Pageaux, B., Lepers, R., Dietz, K. C., & Marcora, S. M. (2014). Response inhibition impairs subsequent self-paced endurance performance. *European Journal of Applied Physiology*, *114*, 1095-1105.
- Wilson, K., Head, J., & Helton, W. S. (2013). Friendly fire in a simulated firearms task. *Proceedings of the Human Factors and Ergonomics Society Annual Meeting*, 57, 1244-1248.

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# Acknowledgements

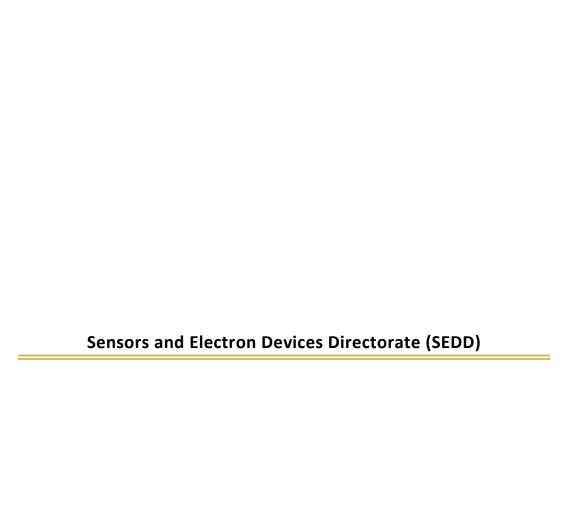


The author wishes to acknowledge the mentorship of Dr. Matthew Tenan and Dr. James Head.

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U.S. Army Research, Development & Engineering Command

# **Bio-Hybrid Fuel Cells** for Waste Mitigation



#### **TECHNOLOGY DRIVEN. WARFIGHTER FOCUSED.**

Marcus Benyamin University of Maryland, College Park Junior, Chemical Engineering & Mathematics

Mentors: Dr. David Mackie & Dr. Justin Jahnke BioTechnology Branch

(U//FOUO) 07 August 2015



## **Objective & Outline**



# Summer Objective: Design, build, and test a flowing vaporfed bio-hybrid fuel cell system for wastewater treatment

- Introduction
  - Army Motivation
  - Direct Ethanol Fuel Cells and Bio-Hybrid Fuel Cells
- Design of System
  - Setup
  - Predictions and Testing
- Results
  - Kinetic data, flow rate data, and reactor model
  - Power vs. Voltage
  - Long-term operation of BHFC system
- Conclusions and Future Work

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# **Army Motivation**

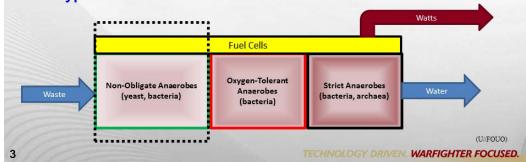


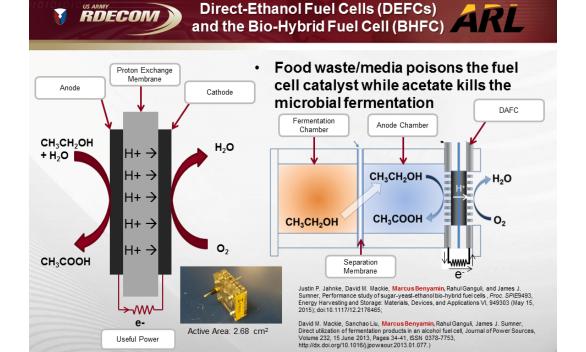
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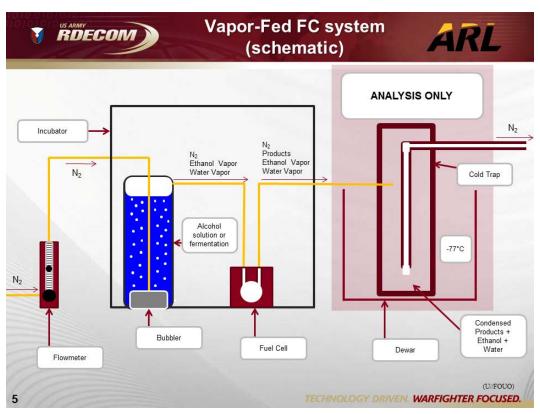
- Waste to Water and Watts (WWW) for the Forward Operating Base (FOB)
  - Requirements: Small scale, mobility, stealth, low-energy
- · Microbial Processing of food waste
  - Multi-stage processing generates clean water and chemicals/fuel as byproducts



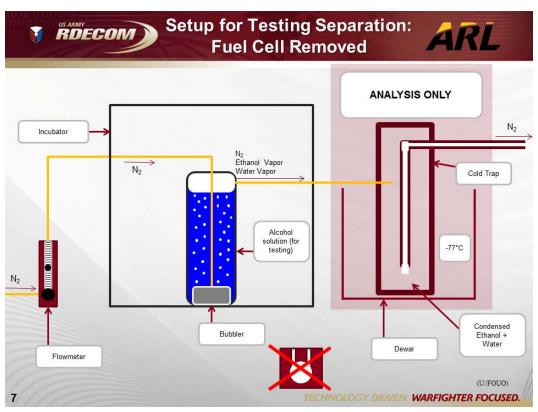
Photo Credit: Karen Parrish, DoD

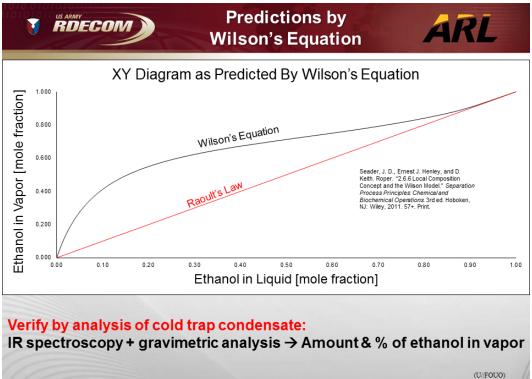


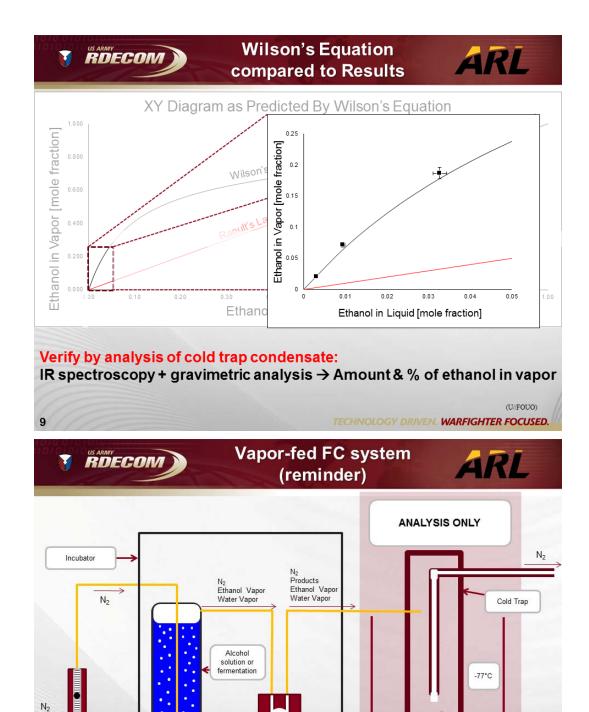












Flowmeter

10

Bubbler

Fuel Cell

Condensed Products + Ethanol +

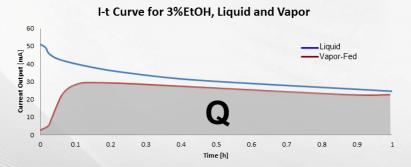
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#### RDECOM Product Analysis & I-t curves AR Combining analysis of condensate and electrochemical data, we can: -Calculate a mass balance for the fuel cell to determine crossover losses -Examine product distribution at varied voltages and temperatures -Determine conversions for ethanol I-t Curve for 3%EtOH, Liquid and Vapor 60 50 Liquid Vapor-Fed 40 20 Current Output ( 10 0.1 0.2 0.5 0.3 0.6 0.7 0.8 0.9 Time [h] 11 TECHNOLOGY DRIVEN. WARFIGHTER FOCUSED.

# Product Analysis & I-t curves ARL

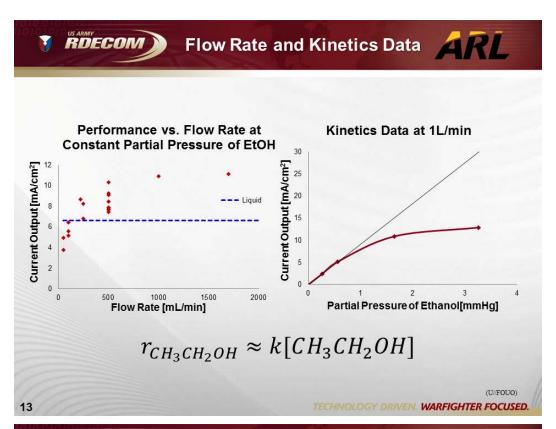
#### Combining analysis of condensate and electrochemical data, we can:

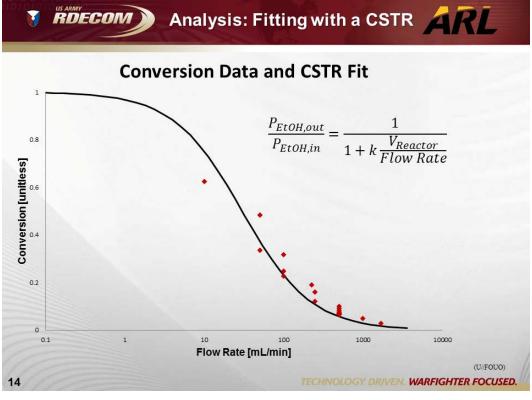
- -Calculate a mass balance for the fuel cell to determine crossover losses
- -Examine product distribution at varied voltages and temperatures
- -Determine conversions for ethanol

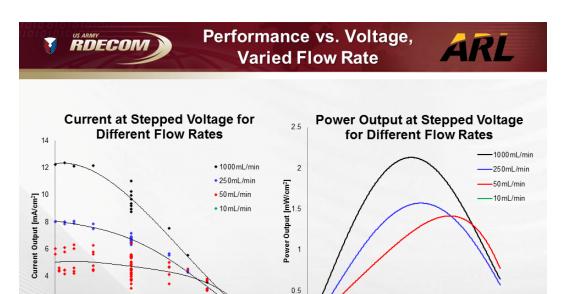


Q → # electrons → # moles reacted → % conversion & mass balance

Most of performance data can be taken with only the electrical measurements.









0.6

0.1

0.2

0.3

Voltage [V]

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0.4

0.5

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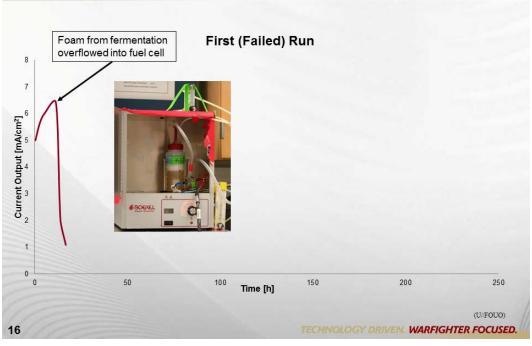
0.6

0.5

0.4

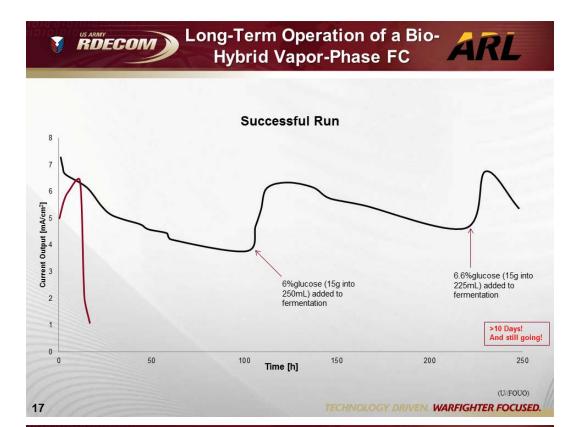
0.3

Voltage [V]



0.1

15



# RDECOM

# Conclusions and Future Work



#### Conclusions:

- Built and tested a novel vapor-fed bio-hybrid fuel cell
- Performance is comparable to that of liquid-fed fuel cell
- Flow rate and performance data fit to CSTR reactor model
- Optimal voltage for peak power output depends on flow rate
- Extended BHFC run time from <24 h to 2 weeks

#### **Future Work:**

- Kinetics and product distribution at elevated temperature
- Lower-energy vapor generation
- Microbial consortia to digest simulated food waste

#### Acknowledgements:

- Dr. David Mackie and Dr. Justin Jahnke
- Dr. Jim Sumner and the Biotechnology Branc

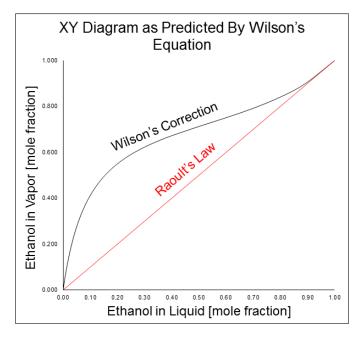


18 · ARL, ASEE, and CQL



# Supplemental: XY Diagrams & Wilson's Equation





Raoult's Law 
$$y_a P = x_a P_a^{sat}$$

Wilson's Correction

$$y_a P = x_a \gamma_a P_a^{sat}$$

$$\gamma_a = \gamma_a(T, x_a)$$

(U//FOUO)

### Supplemental: Langmuir RDECOM Adsorption and the Rate Equation **ARL**

 $r_{CH_3CH_2OH} \approx k[CH_3CH_2OH]$ 

For Langmuir Adsorption:

$$r = \frac{kK_{EtOH}P_{EtOH}K_{W}P_{W}}{[1 + K_{EtOH}P_{EtOH} + K_{W}P_{W} + K_{CH3CHO}P_{CH3CHO} + K_{AcOH}P_{AcOH}]^{2}}$$



# Supplemental: Variability in Fuel Cell Testing



- Fuel Cell has intrinsic variability in performance
- Operating at "standard conditions" before varying parameters reduces variability





# Supplemental: Mass Balance Results



- Cold trap condensate compared to I-t data
- · Results:
  - Yield of acetic acid was nearly quantitative with current output
  - <5% of product was CH3CHO and CO2
  - Loss of ethanol through the PEM can be bound to <10%</li>

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# Accelerated Lifetime Testing on Porous Silicon

Sauradeep Sinha, 1<sup>st</sup> summer Junior Chemical Engineering major at UMD Mentor: Dr. Nick Piekiel July 27, 2015

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#### **Porous Silicon**



#### Overview:

- Porous Silicon (PS) is a high surface area (>900 m²/g) material, formed from bulk silicon (Si)—most common substrate for MEMS and electronics.
- · Typically has nanometer scale pore size
- Small pores and high surface area make it attractive for a number of applications including solar cells, biosensors, or energetic materials.

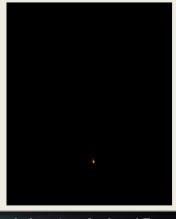
#### Porous silicon as an energetic material:

$$nSiH_2 + (1-n)Si + \frac{\left(2+n\right)}{4}NaClO_4 \rightarrow SiO_2 + NaCl + nH_2O + heat$$

- Porous silicon + oxidizer (NaCIO<sub>4</sub>, MgNO<sub>3</sub>, sulfur, etc.) = high energy density system
- · Highly tunable reaction rate
- · Rapid combustion (3600 m/s) possible
- Low energy initiation, 10's of μJ

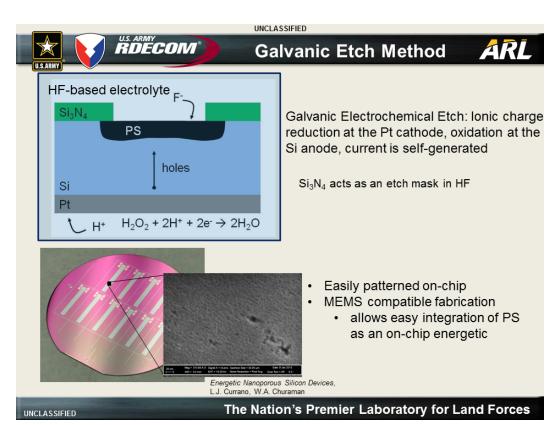


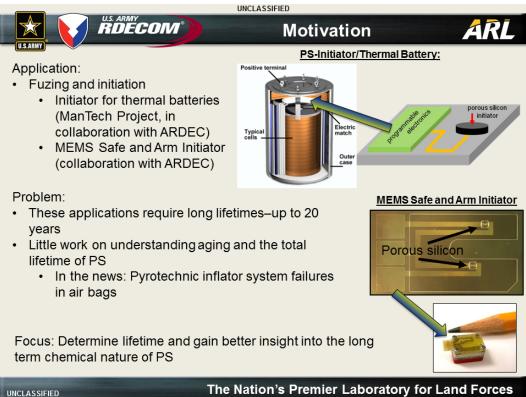




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# Sample Fabrication

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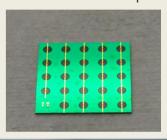
Start with basic silicon wafer with a protective nitride layer and platinum (cathode for etch).

Selectively etch nitride (DRIE) to pattern in a design and apply gold bridgewires through sputter deposition.

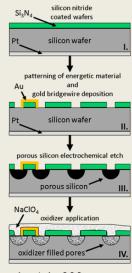
Place in hydrofluoric acid solution for porous silicon etch.

Singulate 2 mm PS regions and electrically connect them to a dual in-line package.

Oxidizer was added to the pores and dried.







Approximately 300 devices have been tested.

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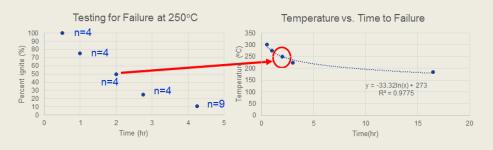
Experimental Methods



# Accelerated aging tests

Samples are aged by baking at a specified elevated temperature and electrically ignited at low voltage for set intervals of time until failure point is reached.

- Needs to last 20 years
- Accelerated lifetime tests
  - High temperature, heat to failure, mimics long term conditions



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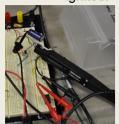




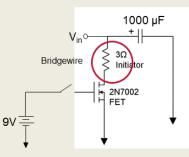
### **Experimental Methods**



- Electrical testing: Recorded current and voltage through the bridgewire during ignition
  - Measure power, energy and time to burst when devices are electrically ignited.







- · Differential Scanning Calorimetry (DSC):
  - Analyze endothermic and exothermic events of PS along a temperature profile.



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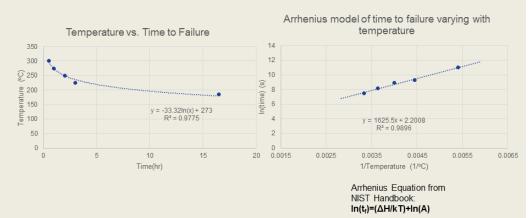
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#### **Failure Times**



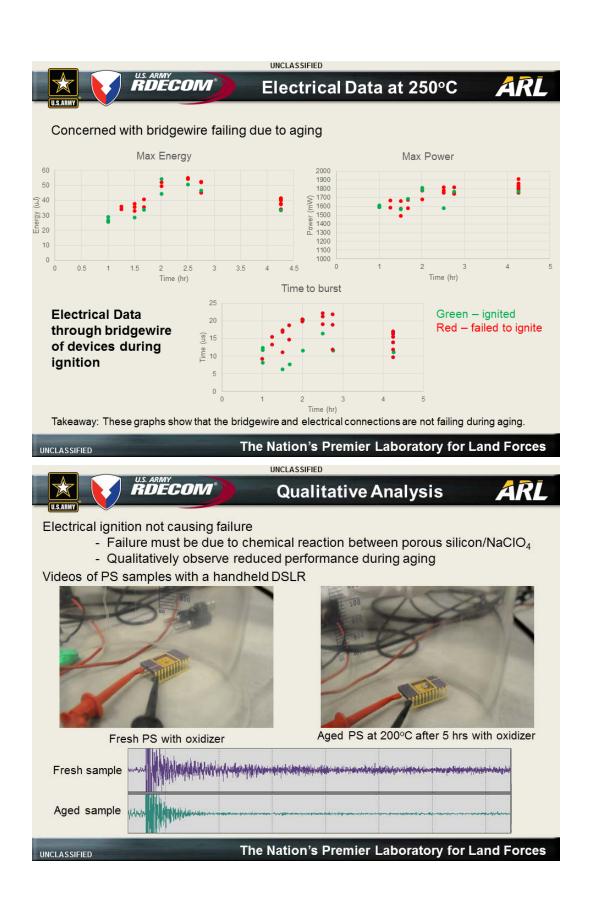
Determination of failure times, which are the time points when at least 50% of the packaged devices do not ignite at a given temperature

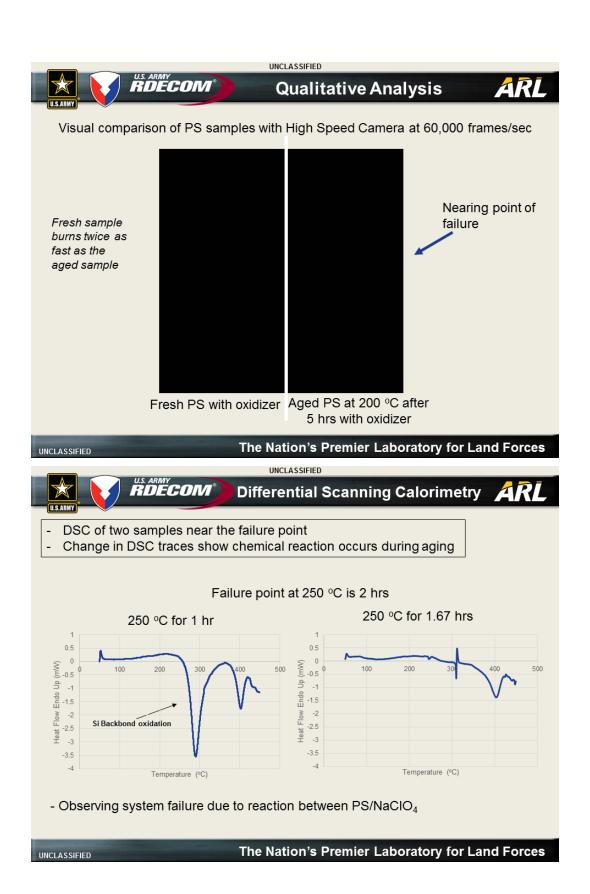


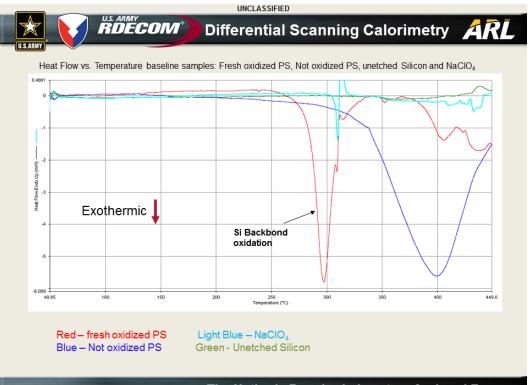
Number of devices tested: At least 20 devices were tested per experiment at a specified temperature Estimated lifetime at 20 °C using Arrhenius model: 23 years

What is causing failure?

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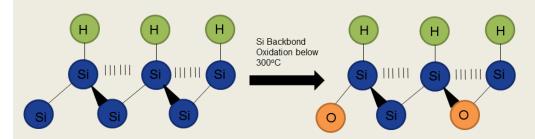
## Si Backbond Oxidation



 Collin Becker's paper Thermal Analysis of the Exothermic Reaction between Galvanic Porous Silicon and Sodium Perchlorate notes Si backbond oxidation occurs below 300 °C.

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Backbond oxidation is believed to be a crucial step for ignition.



 When this oxidation occurs during aging, it consumes silicon fuel, thus reducing performance during ignition (or can prevent ignition).

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### Conclusions



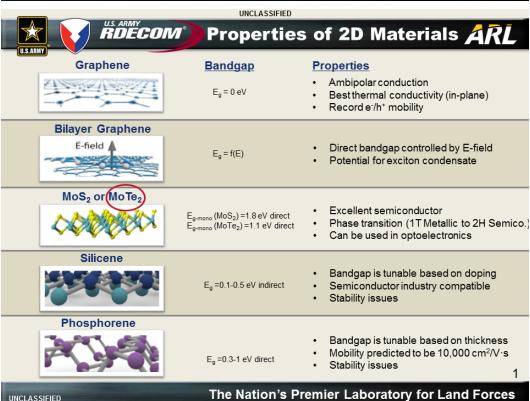
- Investigated lifetime of PS through accelerated aging tests in support of mission critical Army programs
- · Obtained an estimated lifetime of PS at ambient conditions ~ 23 years
- Demonstrated aging affects chemical nature of PS
  - · Electrical data showed no effect on electrical connections
  - · DSC showed evidence of impacting Si backbond oxidation
- Study shows importance of Si backbond oxidation in ignition and knowledge can be used in processing and storing PS+oxidizer systems
  - When integrating with other MEMS devices or fabrication techniques, we now have temperatures guidelines for processing



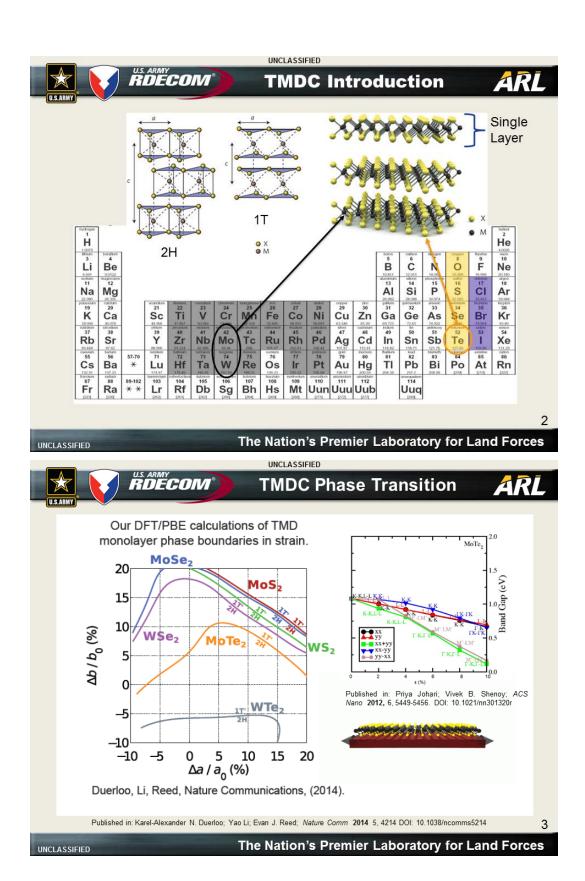
- · Future studies:
  - · Obtain more failure times at varying temperatures
  - · Humidity chamber experiments on packaged devices

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## **Project Outline**



#### **Project Goals:**

- Modulate the bandgap of MoTe<sub>2</sub> by alloying with WTe<sub>2</sub>.
- Adjust stoichiometry to tune metal-to-semiconductor phase transition temperature.
- · Develop unique device fabrication techniques.

#### **Background Motivation and Relevance for ARL/Army:**

- Could offer a route to sensitive 2D infrared detectors.
- · Possible applications in 2D thermally sensitive devices.
- · Non-volatile memory.
- Strain modulated transistors.

#### Technical Challenges:

- · Producing selective stoichiometry.
- Analyzing and understanding the photon-phonon interactions via Raman.
- Observing the bandgap and gradual transition into metallic phase.
- · Creating electrical devices to apply thermal energy or strain.

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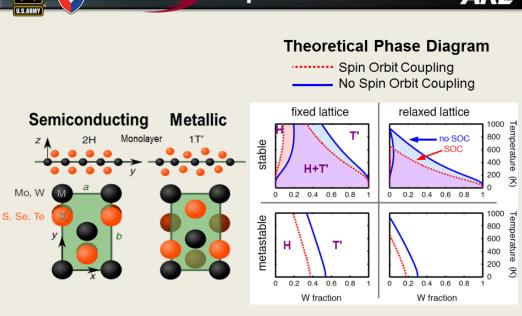
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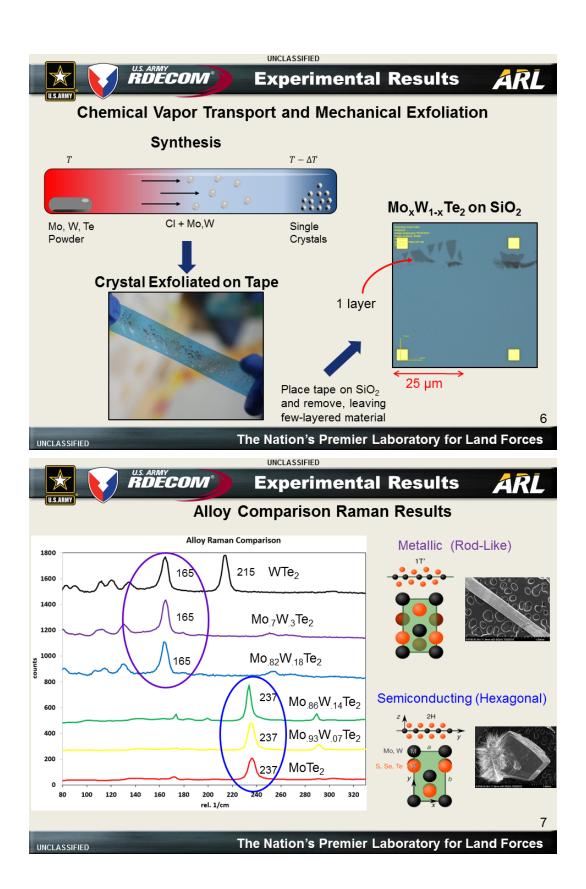
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U.S. ARMY ROECOM Experimental Results

ARL



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## **Experimental Results**

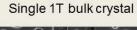


#### **EDX Results**

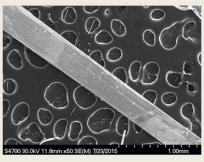
Phase	Mo Atomic %	W Atomic %	Te Atomic %	W:Mo Ratio	Overall Stoichiometry
1T'	23.5	11.0	65.4	.47	Mo <sub>.68</sub> W <sub>.32</sub> Te <sub>1.9</sub>
1T'	23.6	9.6	66.8	.41	Mo <sub>.71</sub> W <sub>.29</sub> Te <sub>2</sub>
2H	28.7	4.6	66.8	.16	Mo <sub>.86</sub> W <sub>.14</sub> Te <sub>2</sub>
2H	29.8	2.8	67.5	.09	Mo <sub>92</sub> W <sub>08</sub> Te <sub>2.1</sub>

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2H crystal with 1T growing from the edge







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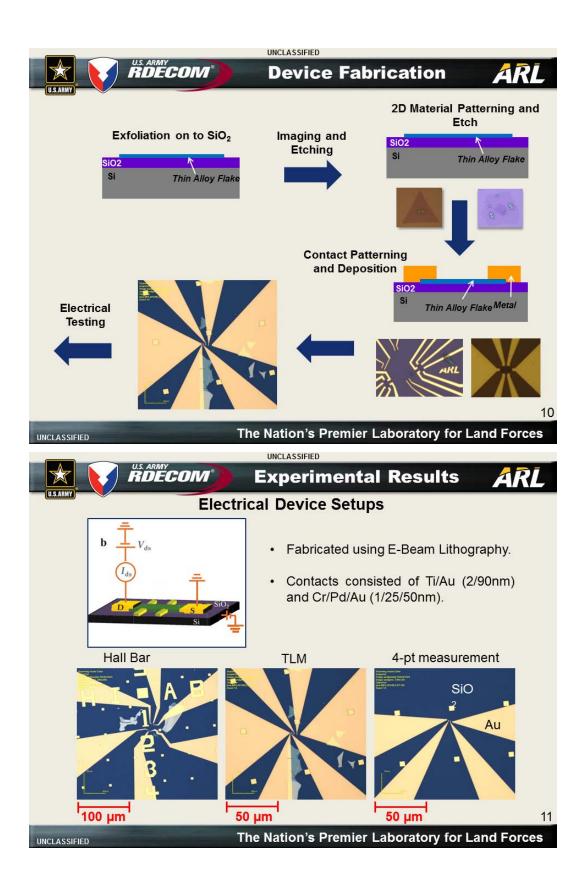
## **Experimental Results**



## Phase transition via laser exposure

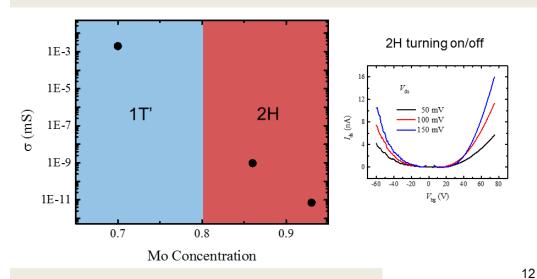


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## Electrical Conductivity for 2H and 1T



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Summary



- We have synthesized a variety of alloys for the  $Mo_xW_{1-x}Te_2$  system, resulting in both the 2H and 1T' phase (prepared at FSU in preparation for ARL internship).
- · An initial study of the stoichiometry has been carried out.
- The alloys have been examined using Raman spectroscopy. We have found various peaks, which are associated with the 1T' and 2H phases for MoTe2.
- We have observed a phase transition via laser heating.
- Devices were fabricated for characterizing electrical properties of the alloys.
- The alloys have been examined electrically, and show semiconducting behavior for low concentrations of W to Mo and semi-metallic for higher concentrations.

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#### **Future Work**



- · Temperature dependence of current 2D materials using a graphene heater.
- · More materials characterization (TEM, TOF-SIMS, XPS, XRD, and EDX).
- Further synthesis and tuning of the phase transition from growth.
- Temperature and polarization-dependent Raman analysis.
- Contact optimization for more reliable electrical measurements and more electrical measurements.
- · Refining laser patterning of 1T' phase.
- Strain-device engineering or thermal device engineering to induce phase transition from 2H to 1T'.

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## **Acknowledgments**



I would like to thank ARL for the opportunity to conduct interesting and meaningful research as an intern.

I would also like to acknowledge ARO and the NSF for facilities and support before arriving at ARL.

Thanks to those who helped me with this project:

Daniel Chenet\* Sina Najmaei

Tyler Klarr\* Madan Dubey (Team Leader)
Alex Mazzoni Luis Balicas (PHD Advisor)

Matthew Chin (Mentor)

Matthew Hwee Robert Burke

(\*contributed towards Raman, composition characeterization, and planning

project)

And a particular thanks to Alexander Duerloo and Evan Reed for providing theoretical calculations.

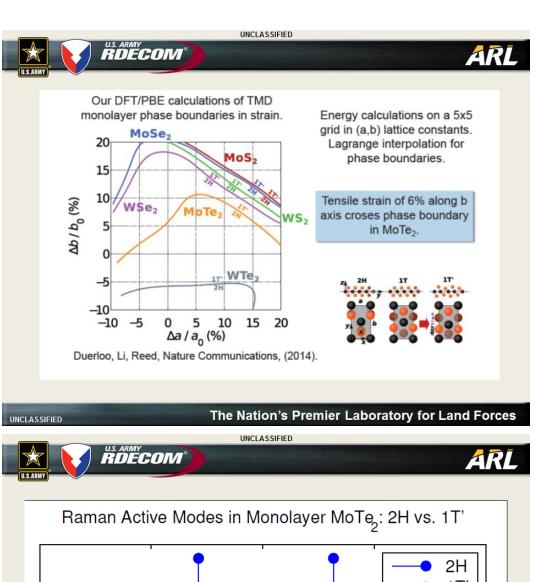
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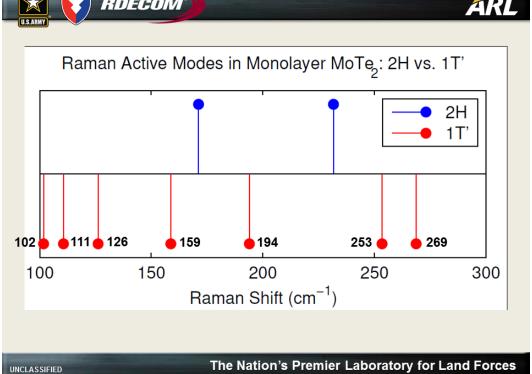
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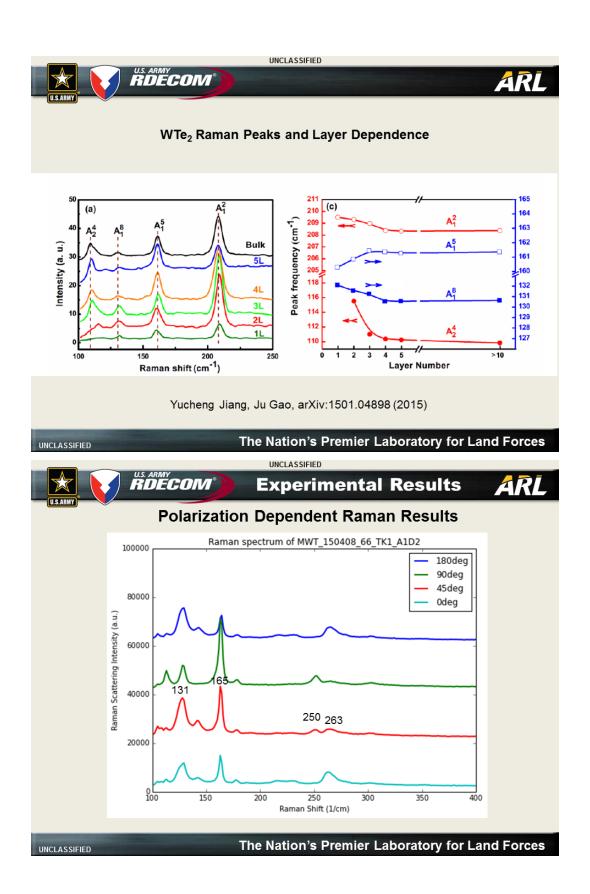


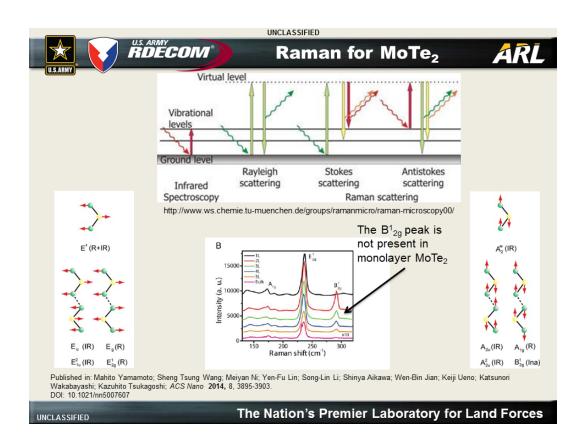
## Thank you for your time.

#### The Nation's Premier Laboratory for Land Forces UNCLASSIFIED UNCLASSIFIED U.S. ARMY **RDECOIVI Experimental Results** Electrical Conductivity for 2H and 1T 1T' Phase Alloy 2H Phase Alloy 2H Phase Alloy (Cr/Pd/Au 280nm SiO<sub>2</sub>) (Ti/Au 100nm SiO<sub>2</sub>) (Cr/Pd/Au 280nm SiO<sub>2</sub>) -15 V -30 V -30 V 150 -40 V $I_{\rm ds}$ ( $\mu$ A) I (nA) /<sub>ds</sub> (nA) -50 V 100 $\sigma_{\text{off}} = .95 \text{ nS}$ 0.2 $V_{\sf ds} \, ({ m mV})$ $V_{\rm ds}\left({ m V}\right)$ $V_{\rm ds}\left({ m V}\right)$ /<sub>dt</sub> (nA) $I_{\rm ds} \, (\rm nA)$ /<sub>ф</sub> (µА) - 100 m V 20 40 $V_{\mathrm{bg}}\left(\mathbf{V}\right)$ The Nation's Premier Laboratory for Land Forces UNCLASSIFIED









Vehicle Technology Directorate (VTD)

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## **Ethan Corle**

Department of Aerospace Engineering
The Pennsylvania State University

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**Outline** 



- Motivation
- Background
- Methodology
  - RCAS Model
- Results
  - Fan Plots
  - Load Comparisons

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## Motivation

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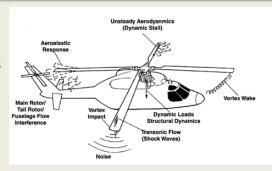


## Compromised design of rotor blades

 Differing aerodynamic conditions across flight envelope.

### Active rotor technologies

- Dynamically change airfoil characteristics to alter blade loading
  - Both aerodynamic and structural effects
  - Used to increase performance, reduce vibrations, and reduce noise





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### **SMART Rotor**



## Smart Material Advance Rotor Technologies (SMART) Rotor Program

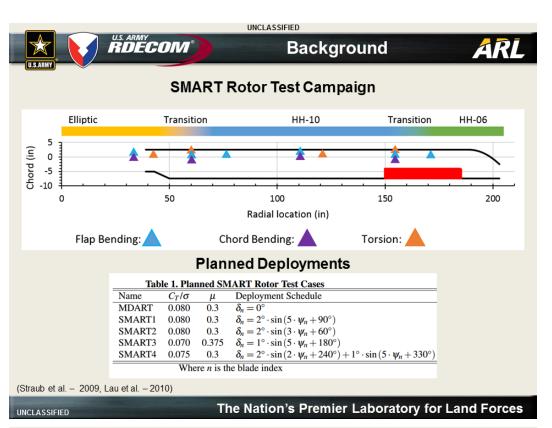
- · DARPA Helicopter Quieting Program
- · Army, NASA, Boeing
- Designed to improve and validate the current state-of-the-art in active rotor modeling
- Accurate models can provide reliable predictions prior to expensive testing

End Goal: Investigate active flap aeromechanics and utilize understanding to make optimized flap deployment schedules





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Previous Work



## Comprehensive Analytical Model of Rotorcraft Aerodynamics and Dynamics (CAMRAD) II Modeling (Kottapalli – 2010,2011)

- Predictions:
  - · Flap hinge stiffness sensitivity
  - · Alterations to airfoil tables

#### Coupled fluid-structure modeling (Potsdam et al. - 2010)

- OVERFLOW 2.0aa and CAMRAD II
- Challenging multidisciplinary problem
- · Little improvement over comprehensive analysis

#### **Current state of the art**

- · Large discrepancies between analysis and test data
- · Aeromechanics of active flap not fully understood

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## **Computational Tools**

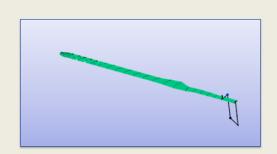


## The Rotorcraft Comprehensive Analysis System (RCAS)

 Army-owned multidisciplinary, flexible multibody for rotorcraft aeromechanic analysis

#### **RCAS Structural Model**

- Geometrically exact
  - · Control system
  - · Blade root connections
  - Flap connections
- · Nonlinear beam elements
  - · Sectional material properties
  - · Separate elements for blade and flap segments

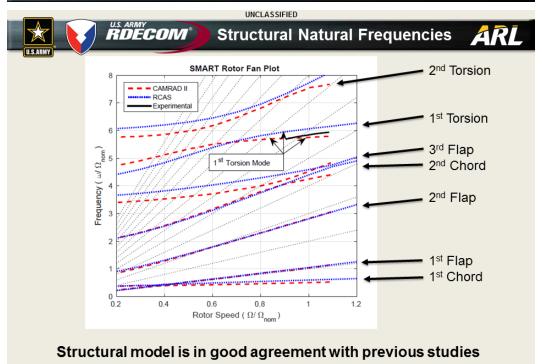


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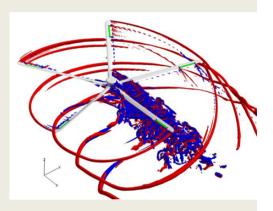


## **Computational Tools**



## **RCAS Aerodynamic Model**

- Nonlinear, unsteady
- Computationally efficient
- Empirical model for blade/flap effects
- Trimmed to fixed  $C_T/\sigma$  and measure pitch and roll moments



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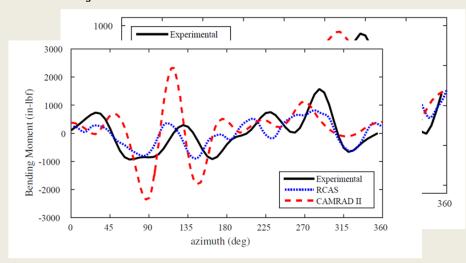
Results

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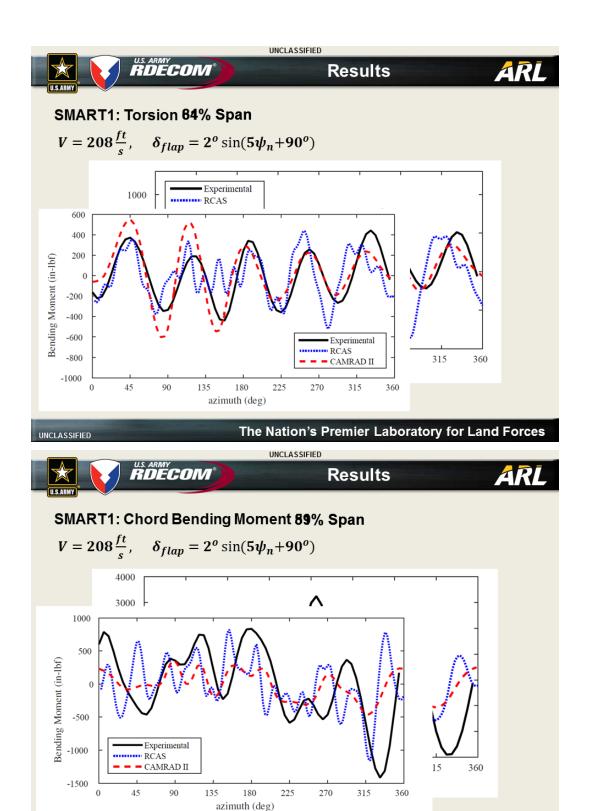


## SMART1: Flap Bending Moment 89% Span

$$V = 208 \frac{ft}{s}, \quad \delta_{flap} = 2^o \sin(5\psi_n + 90^o)$$



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#### **Conclusion & Looking Forward**



#### Conclusion

- · First RCAS SMART rotor model developed and validated
  - · Good correlation with structural model
  - · Fair correlation with experimental loading data
- Higher harmonic content observed in chordwise bending and torsional loads
  - Blade flap interference model not adequate to complex aerodynamic interactions

#### What's Next?

- Finish baseline cases for other SMART deployments
- Investigate alternative flap modeling
- Implement Helios for CFD/CSD predictions

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**Acknowledgements** 



#### Mentors:

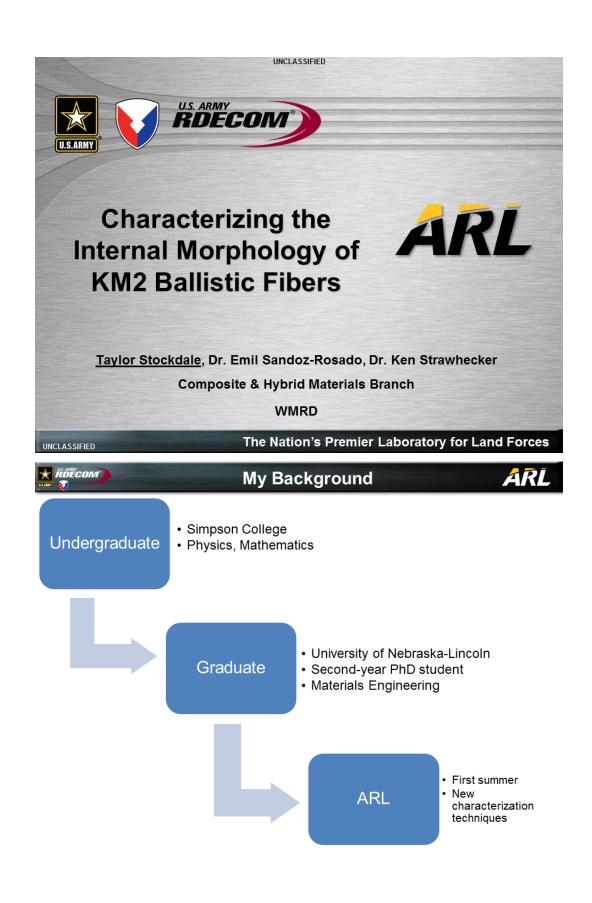
- Rajneesh Singh
- Hao Kang
- Matthew Floros
- · Sven Schmitz

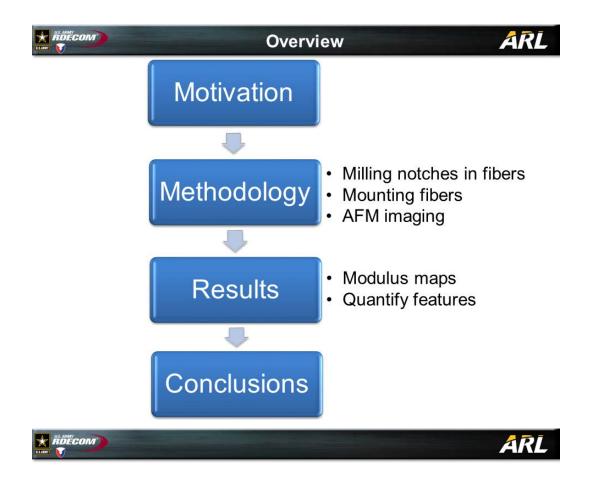
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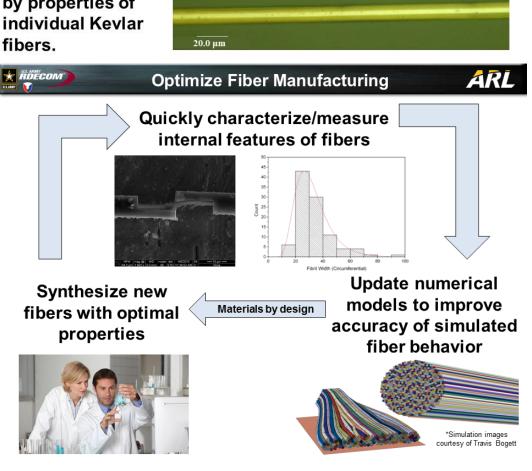
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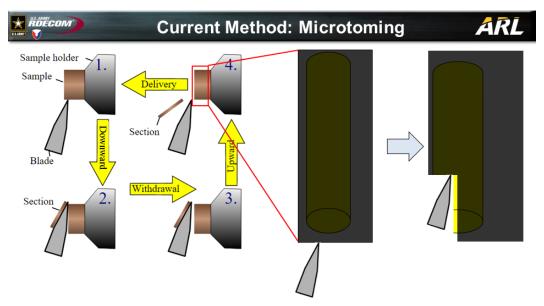




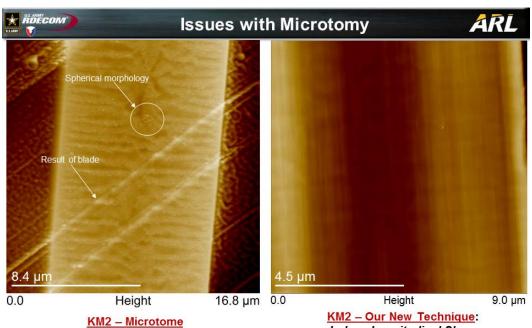
# **Motivation**







- Very little work done to characterize internal features of high performance fibers
- Previous studies utilize microtomy to observe internal features of Kevlar and UHMWPE
  - Dobb et al. Journal of Polymer Science (1977), McDaniel et al. Polymer (2015)

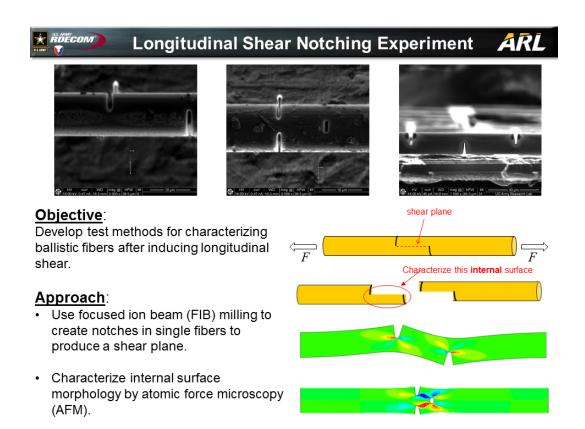


- Lengthy process (≥24 hrs/sample)
- Sorting of features
- Odd spherical morphology develops over time
- Induce Longitudinal Shear
- Time-efficient (<2 hrs/sample)</li>
- No mechanical agitation of internal features
- · No time-related effects

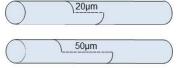




# Methodology

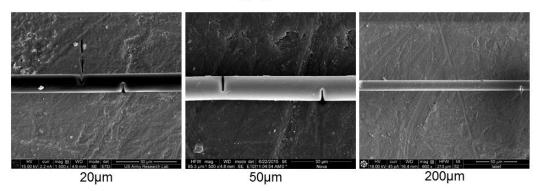


## Method: FIB Notches for Longitudinal Shear ARL



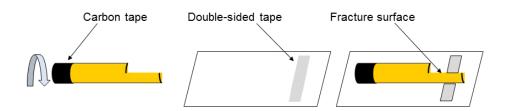
200µm

- Notches eliminate longitudinal strength of fibers making them extremely fragile
- · Fibers fractured in tension
- After fibers are fractured they must be mounted in the correct alignment for imaging





- Fix back end of fiber to carbon tape allowing rotational freedom.
- Use optical microscope as visual aid and rotate fiber until fracture surface is facing up.
- Fix tip of fiber to double-sided adhesive tape to secure fiber for imaging.

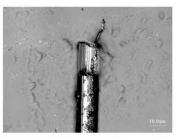




## **Method: Mounting Fibers for Imaging**

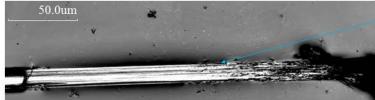


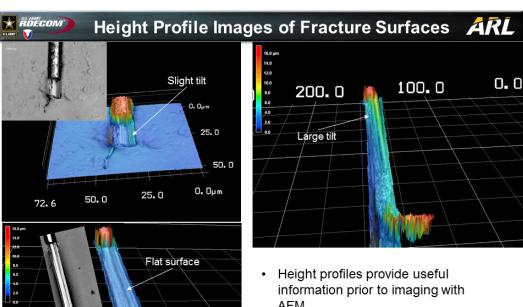
- · Initial imaging performed using Keyence 3D laser scanning confocal microscope.
- · Height profiles are generated to confirm fracture surface alignment is maintained after mounting.



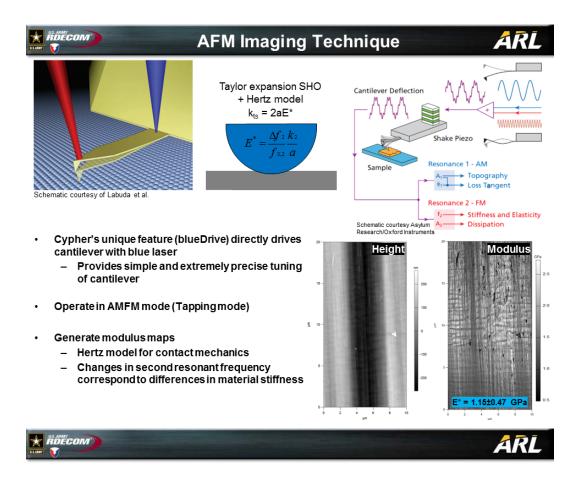


Onset of fibrillation

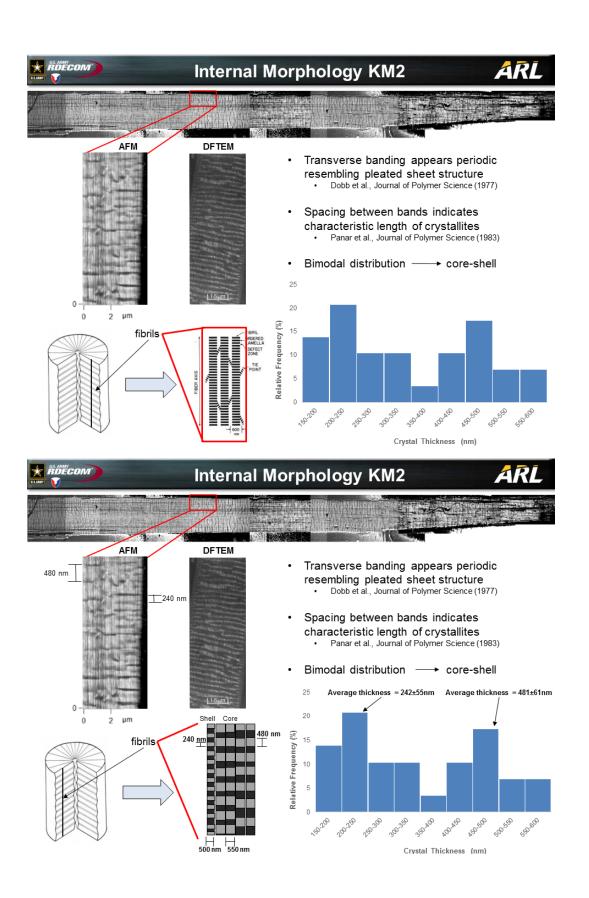


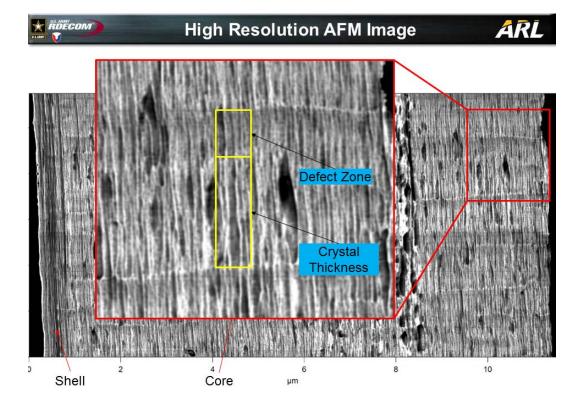


- AFM
  - Confirm fracture surface alignment
  - Fracture surface step size
  - Location of features of interest



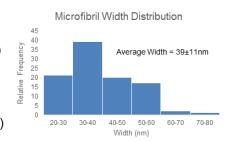
# Results

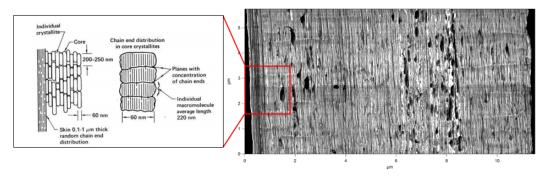






- High resolution scan shows microfibrillar structure, which resembles chain-end model of poly(p-phenylene terephthalamide) (PPTA) fibers.
  - Morgan et al., Journal of Polymer Science (1983)
- Modulus of core = 1.15 GPa
- Modulus of shell = 0.84 GPa (~25% reduction)





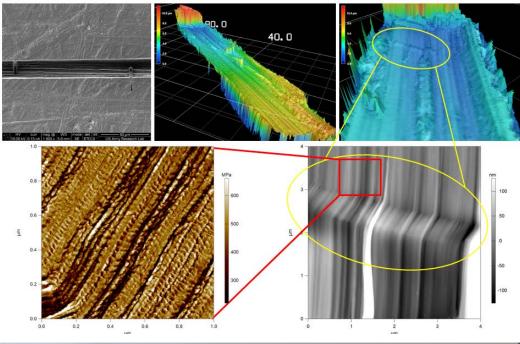
• Technique works for KM2 – what about other fiber systems?



## Other Fiber Systems

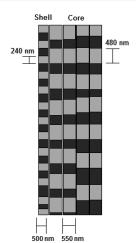


Technique applied to observe internal morphology of UHMWPE fibers - Dyneema SK76

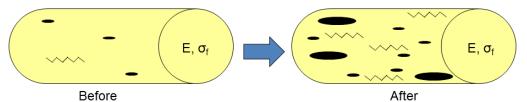


## Connecting Morphology to Fiber Properties ARL





- Mechanical properties known for single KM2 fibers
- Next Step: Correlate changes in internal morphology to changes in mechanical properties





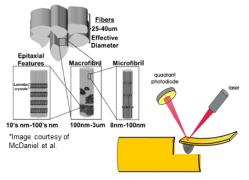


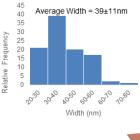
# Conclusions





- Successfully induced longitudinal shear in single Kevlar KM2 and UHMWPE fibers using FIB notch technique.
- Internal features of KM2 resemble those observed in Kevlar 49 via DFTEM.
- Our new technique is more time-efficient and less disruptive than microtomy.
- Technique can quantitatively show how changes in internal morphologies effect overall mechanical properties.







## Acknowledgements



Eric Wetzel

- Jon Ligda
- Emil Sandoz-Rosado
- Randy Mrozek
- · Ken Strawhecker
- ASEE

• Paul Moy

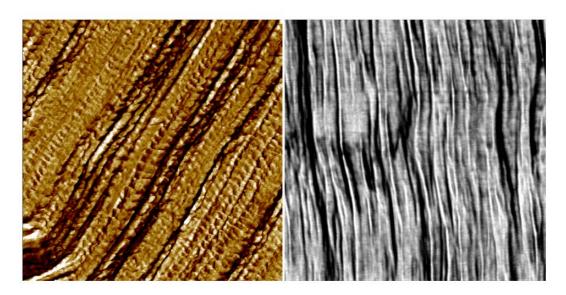
· CQL

Josh Taggart





## **Questions?**





### References



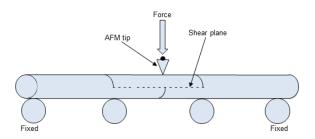
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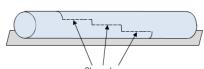


## **Shear Experiment Concepts**



- TEM Grid 3-point bending
  - Short beam shear test uses 3 point bend test with span to thickness ratio of about 4:1 for inducing pure shear
  - 400 mesh TEM grid provides span:tk of about 5:1
- · Stepwise shear surfaces
  - Provide through thickness observation of internal morphologies





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